Cybercare: Combining Healthcare and Cyberspace in the 21st Century

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Abstract-**In this paper, we discuss the origins of the modern hospital-based tertiary care system. We define how this system was a product of a large-scale medical disaster that prompted the invention of the modern hospital. We will then similarly describe the disaster that prompted the beginning of telemedicine. Following, we review the history of telemedicine and the development of telesurgery and present the state-of-the-art in telesurgery and other advanced telemedicine technologies. We will then define cyber through a discussion of cybernetics and cyberspace. We present the concept of the digital physician and a cybercare vision of a new healthcare system. We will then predict what type of large-scale medical disaster would prompt the creation of a cybercare healthcare system. Finally, we discuss the challenges to be faced in the 21st century.**

I. INTRODUCTION

In today's healthcare system the hospital provides an environment for direct care to the patient. The present hospital care model is very old. Direct care is still the present economic model for the delivery of care. Hospitals provide the environment for most acute intensive medical and surgical care. We expect that care will shift from the hospital to the home and from the physician to the family with telemedicine supporting this trend in the 21st century.

II. HISTORY OF THE HOSPITAL

The modern hospital has its origins in ancient Rome. In the year 27 A.D. a coliseum was built outside of Rome on faulty ground and collapsed during a gladiator contest. This resulted in from 20,000 to 50,000 casualties. The Roman system of healthcare was overwhelmed by this event. At the time casualties had been cared for in the senators home where clinics could handle up to 20 to 50 sick slaves or soldiers at a time. A sudden influx of 20,000 to 50,000 at one time is considered a catastrophic medical disaster and cannot be handled in such an environment. The coliseum disaster overwhelmed the Roman Empire.

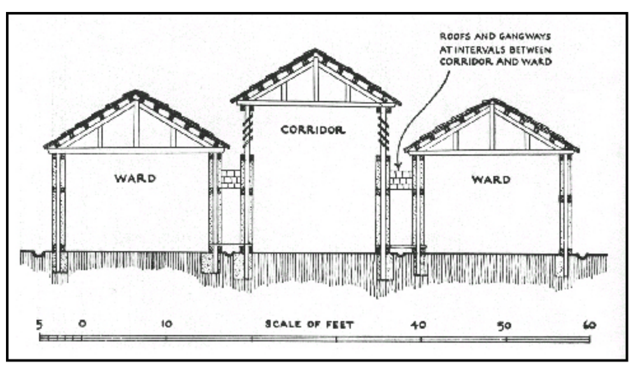
The Romans therefore invented a 'valetudinaria'. This is what we call in modern days a hospital. They moved care from the homes of the senators to a major medical facility or multiple major facilities. Soon the military also adopted this model for the entire Roman Empire. Hospitals were used to provide care throughout the frontier and were present in every major fort from Italy to England. Romans rapidly constructed hospitals throughout the frontier in all of their major forts [1].

Hospitals allowed the separation of healthy soldiers from the injured. Thus, present hospital design of the ward system was a Roman invention. Moreover, the layout of a hospital designed in 1950 would be almost identical to a Roman facility. More recent civilian hospitals have moved from large wards to double and single rooms. Military hospitals also follow this model today. However, a new approach in military medicine is to move the hospital into the 21st century battlefield. Though in reality, the concept is to connect the frontlines to the rear echelon facilities through telemedicine.

III. HISTORY OF TELEMEDICINE IN THE UNITED STATES

Despite that there are many claims as to the origins of telemedicine in the United States, my version is based on a response to a large casualty event that occurred at Logan airport in Boston in the 1950's. In this event a plane crash caused numerous injuries to which care could not be delivered. Boston is home to one of the finest healthcare systems in the world, but this system could not be moved in an emergent way to the airport. Likewise, the casualties could not be moved from the airport to the hospitals. The tunnel that connects the city to the airport provides an obstruction to physically connecting the two sites in a medical disaster.

Following the disaster Thomas Sheridan at MIT was asked to provide a report on what technologies would be needed to correct these problems. He was asked to develop technologies that could be used to connect the airport to the hospitals. Sheridan found that most of these telemedicine technologies had already been developed for the nuclear industry through teleoperations. Further development was then done under the auspices of NASA during the 1970's and later. In fact, over the past 40 years telemedicine has gone through three phases of project funding to develop better technologies, in spite of the fact that the limitation has not been technology but rather our government and its policies [3].



Section through the North wing of the Inchtuthil army hospital [1].

In the 1970's NASA was interested in how to provide healthcare in space. How were they going to provide

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Abstract

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astronauts with high-level care while they were in orbit around the Earth. The solution was felt to be telemedicine and telesurgery, where from Houston a physician or surgeon could provide care to an astronaut in the space station, space shuttle or other vehicle. A number of problems would have to be overcome to accomplish this technological feat. NASA was willing to fund projects to address these problems [2].

I became involved in these projects in the 1980's and was asked to help develop a telesurgery system. I felt that the first step was to do surgical simulation. I wanted to create a virtual reality system that could be used for training and eventually for mentoring. This was done with Scott Fisher at NASA at the Ames facility in California. The goal was to create an environment in virtual reality with two or more players that provided telepresence for vision, hearing and touch.

We created this environment in 1989 with a simulator for leg surgery created in conjunction with Scott Delp and Steve Pieper. This combined the biomechanics model of the lower extremity that Scott Delp had developed and was put into practice by Steve Pieper within the virtual environment workstation that Scott Fisher had developed. This simulator allowed the user to perform tendon transfers within a virtual environment [4][5].

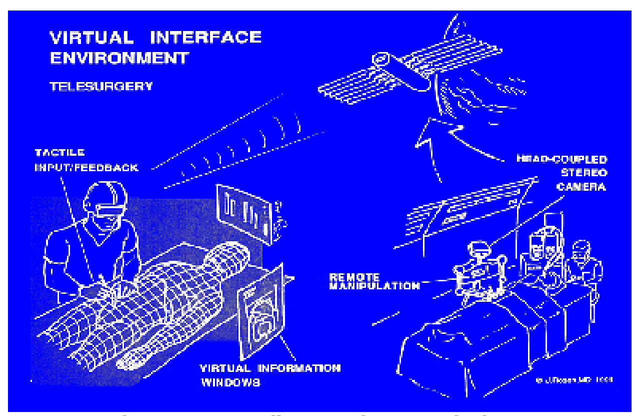
In the 1990's the funding source shifted to DARPA with whom we were able to develop a limb trauma simulator for special forces. Scott Delp and Peter Loan at Musculographics directed this project. They developed a lower extremity simulator using the visible human dataset [6]. A high-resolution model of the lower extremity was made that could simulate the impact of a gunshot wound on the thigh. This would include the physical damage as well as the physiological and biomechanical effects of the injury on the soldier. The simulator would be a training device for soldiers to teach them how to take care of an injury, including debridement of the wound in the battlefield. The simulator included a virtual reality system along with force-feedback haptics for the operator's hands.

During the same period of time I was the advisor to a number of thesis projects with David Zeltzer at MIT on developing a more detailed virtual model of the human body [7]. These included a model of muscle by David Chen [8], a model of skin by Steve Pieper [9][10] and a model of walking by Mike McKenna [11]. The virtual human that walked was a model of biped walking that allowed one to analyze the effect of certain surgeries on ambulation and gait [12].

All of these technologies were combined in a start-up company called Medical Media Systems to create a performance machine. This machine would super-impose a virtual human model on a real patient. This would allow the surgeon to operate on a real patient with their specific virtual data combined in real time in a datafusion type environment. This augmented reality system was first created for a knee arthroscopic surgical system. Multidimensional data about the patient's knee biomechanics could be included along with virtual guides to help with drilling and placing ligaments. Additionally, we used the datafusion performance machine for tumors in the liver [13][14].

The leg trauma simulator was part of a broad battlefield medical program at DARPA run by Richard Satava and Shaun Jones that included a large number of projects, which would revolutionize how we approach healthcare in the 21st century. The lead project in their program continued to be high-level telesurgery from a long distance, providing a surgeon to the 'fox-hole' during a battle. In other words providing high level care to an injured soldier in the battlefield by connecting the rear echelons of care to the forward echelons through telecommunications and ultimately a new application of cyberspace and telemedicine [15].

Through the early funding of the DARPA program from 1993 onwards a robust telesurgery system was developed. It has now been commercialized for civilian use and is beginning to spread throughout hospitals in America and other places around the world. These tele-robots are conceptually similar to the ones that Tom Sheridan studied 40 years earlier. They have been improved and refined for medical use to provide an environment for many different surgical disciplines, including heart surgery [16]. They are usually used a short distance and can be used at longer distances as long as the delay is not greater than approximately 100 milliseconds. Herein is the present limitation of present systems; it is the inherent delays in our telecommunications systems.



Telesurgery via satellite using haptics and robotics.

The DARPA biomedical program provided a vision of a healthcare system based on the digital physician. The digital physician is a physician that converts all of their input from analogue to digital and similarly converts all of their output from analogue to digital. The input includes vital signs, x-rays, real time video, and the patient record. The output includes large and small robots, telerobotics and teleoperations, telemedicine, endoscopy, and other telecommunication systems. The combination of all of these technologies creates something new – cybersurgery. If combined in the proper way they could create a revolution in medical affairs, similar to what was happening as a revolution in military affairs (RMA) [17].

This DARPA program was initiated in 1993, the same year that the Clinton administration was introducing healthcare reform. As part of the healthcare reform efforts I worked with C. Everett Koop, former surgeon general, on demonstrating the viability of a new healthcare system based on telemedicine. We showed that the novel combination of telemedicine, telepresence, telesurgery, virtual reality simulators, and healthcare knowledge embedded in data cubes could create a superior system. This system would allow the patient to receive high-level care in their community by moving the tertiary care doctor from the distant hospital through cyberspace to their 'home'.

We then took this same concept in 1996 and demonstrated it on an inexpensive store-forward system called International Medical Electronic Link (IMEL). In this demonstration we did over 90 real consultations from Katmandu, Nepal to Dartmouth Hitchcock Medical Center in Lebanon, New Hampshire. We demonstrated that a low cost simple system could provide high-level teleconsultations. We have since used this system in other places around the world such as in the Amazon Jungle of Peru (www.imel.com).

IV. CYBERCARE

Richard Satava in 1998 coined the term cybersurgery, and at this juncture it is important to determine the origins and meaning of this term. Cyber is from the Greek word to steer or to govern. Norbert Wiener used the term in the title of his book *Cybernetics* (1948) that discussed the science of control systems, comparing the human and the computer control systems. In 1984 William Gibson in a science fiction book *Neuromancer* coined the term cyberspace. It has become exceeding popular and is defined as an environment of interlinked networks providing access to information and interactive communication systems [17].

Cybercare is more than just telemedicine. It includes in addition to telemedicine, telesurgery, telementoring, and distance learning systems. It includes virtual reality simulators, augmented reality, datafusion, computer patient records, clinical information systems and software intelligent agents [18][19][20]. Though the combining of all of these parts we can create a very special healthcare environment – cybercare.

Cybercare can be seen as a matrix that combines all of the following technologies within a telecommunications space. These technologies include clinical information systems, intelligent agents, telemedicine, telesurgery, virtual reality, and augmented reality. But there is also a seamless bridge between information technologies connected to the physical world through robotics and information technologies connected to the virtual world. These two worlds can be combined in numerous ways. They are simply different ways that information technologies can be expressed either locally or at a distance.

Cybercare is cyberspace plus healthcare. It creates a new environment for healthcare at a distance. It uses present information technology with expanded bandwidth and telecommunications. The bandwidth may be Internet 1 or Internet 2 or even the newer Supernet. It combines both physical and virtual worlds within an augmented reality system. It is this system applied to healthcare delivery in the 21st century.

V. FUTURE CATASTROPHIC MEDICAL DISASTERS

A catastrophic medical disaster is defined as a disaster that involves tens of thousands of casualties. These are patients that will require care in an emergent environment. Like the Roman disaster of 27AD a medical disaster of this size would be a catastrophe that we would not be able to handle with our present resources. The federal response plan, the state plans and the local plans are not prepared for this level of medical catastrophe.

Natural disasters take the form of earthquakes, hurricanes and forest fires. The earthquake in Kobe, Japan in 1995 would qualify as a catastrophic medical disaster (50,000 casualties) and clearly overwhelmed Japan's emergency management system [21]. Fortunately disasters of this size have been infrequent in the 20th century. However, if we look at epidemics one of the largest catastrophes was the influenza pandemic of 1918 that killed from 20 to 100 million people worldwide. It was such a large catastrophe and affected almost everyone that we have tried to remove it from our memories; only recently has it brought much discussion of what were its natural causes. Similarly the plague and smallpox were also large-scale killers in the 20th century but have been felt no longer to be a 'natural' threat in the 21st century.

If we were faced by a new influenza outbreak today we would have possibly over a million casualties in America or more. We lost almost one half a million people to the epidemic in 1918. Influenza is one of the few infections that is contagious and has a 'dandelion' effect. It spreads and continues to spread throughout the population. Almost one hundred years later our healthcare system remains poorly designed to combat such a threat and our increasingly mobile population creates even greater dangers of this epidemic spreading far more rapidly than it did in 1918. Rather than facing this threat, we have chosen as a nation to avoid thinking about how to create a healthcare system that could deal with such a threat.

The response to such a threat requires a national cybercare system based on telemedicine. Possibly it requires an international community where each of the cybercare systems among the major countries are linked together to fight such a threat of a world pandemic like influenza. The question is what will prompt a major change in our present 'modern' hospital based system that has its origins with the Roman Empire.

My hypothesis is that a natural or man-made disaster will force us to shift in a revolutionary way to a better, more robust system. It is unlikely that we will with our present governmental agencies shift in an evolutionary way to a

better system that will protect our population from a catastrophic medical disaster.

VI. CYBERCARE SYSTEM

How would a cybercare system approach a response to a large-scale catastrophic event such as an influenza epidemic whether natural or man-made, i.e. terrorist? Unaffected areas in distant regions would support each affected area. We would need to mobilize most of the healthcare system linked through cyberspace. Local responders would be supported by telepresence and telementoring and in some cases if needed teleoperations. A complex healthcare network would be created, a cybercare system.

If Boston were the first city ‘attacked’ (either by a natural flu or by a man-made terrorist incident) then a number of distant medical centers in the Midwest would be brought on-line to help in the response. The response is based on three major issues. The first is detection of the event. The sooner the event is detected, the sooner the effect of the ‘attack’ can be limited. The second is quarantine – which would have to be done to try to limit the spread of the disease, so that the overall effect of the ‘attack’ did not overwhelm our total available resources. The third is the cybercare system, which is a new federal response system – but really a mega-system. (We will not cover either bio-detection or quarantine in this paper – they will be addressed in the future).

While Boston is under attack, command and control centers will be set up throughout the Midwest to triage the casualties and make decisions on what is the best care possible for those affected by the epidemic. Each command center will handle anywhere from 10 to 1000 casualties depending on their capabilities, expertise, bandwidth, etc. They will use casualty data cubes to assess information coming in on the affected population in Boston [22]. The data cubes will be real time simulators with access to augmented reality. In effect the data cubes can control devices such as robots, teleoperations, and provide telementoring or telepresence to the first responders in Boston.

Many of the first responders in Boston will be affected by the attack and their substitutes will need to be advised on how to handle the disease.

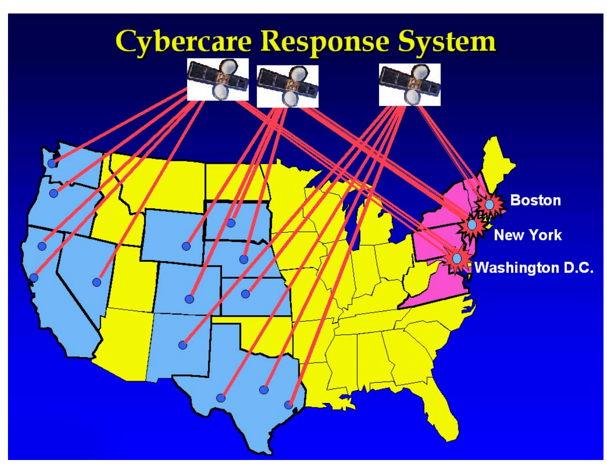
At this point it is likely that the epidemic will have spread to other major population centers such as New York City. Additional sites at a distance will be brought on-line. These will be in the southwest. They will again divide up the areas of New York City that require care. Assignments will be made. Each new command and control center will monitor a data cube with 10 to 1000 casualties and provide the best care possible. In some cases patients can be treated, in other cases they will be beyond care. Resources and logistics will be a severe problem that will need to be continually addressed.

Finally the epidemic spreads to Washington DC and this city is also quarantined. Now, the epidemic is under control. There is no more evidence of spread. All resources in America have been brought into the Cybercare system. The west coast command centers are all active. Both civilian and defense department assets are fully deployed. This includes physical logistics and resources such as water, mobile hospitals, robots, and virtual logistics such as bandwidth, communication systems and software agents.

The system works at the one to one level between local providers in the affected cities and distant experts. It also works at the largest level of gaining control over a large-scale disaster as quickly as possible. The system provides real time simulators to determine on the run what are the best choices for deployment of available resources. It evaluates various scenarios and determines which ones should be implemented. The simulator is an integral part of the overall cybercare system. The simulator will be used to train the players before the event so they understand how it works when the incident occurs and are well rehearsed in what they need to do and how they will need to respond.

VII. CONCLUSION

A cybercare system as described above is a concept only at this time. However all of the individual technologies are available. Although it is unlikely that we will adopt such a



Cybercare system illustrating multiple clinics remotely providing care in an influenza outbreak.

system in an evolutionary way, we will not legislate this system into place under our present system of government. The present government does not feel that they have a mandate to create such a revolution in how we deliver healthcare. There is nothing about the above system that cannot be done.

If we look back to a similar time in history we can use Winston Churchill as a guide. He was deeply troubled with the lack of preparation of England prior to WWII. He felt that it was imperative to prepare and it was the mandate of the government, no matter what the obstacles, to prepare for the inevitable. He stated that it was “The responsibility of Ministers (i.e. government officials) for the public safety is absolute and requires no mandate. It is in fact the prime object for which Governments come in to existence.” [23] We face a similar time in our new century. Although our enemies are not as well defined as those that Churchill faced, our challenges may be greater.

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